Microfilament-Eruption Mechanism for Solar Spicules

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Abstract

Recent studies indicate that solar coronal jets result from eruption of small-scale filaments, or "minifilaments" (Sterling et al. 2015, Nature, 523, 437; Panesar et al. ApJL, 832L, 7). In many aspects, these coronal jets appear to be small-scale versions of long-recognized large-scale solar eruptions that are often accompanied by eruption of a large-scale filament and that produce solar flares and coronal mass ejections (CMEs). In coronal jets, a jet-base bright point (JBP) that is often observed to accompany the jet and that sits on the magnetic neutral line from which the minifilament erupts, corresponds to the solar flare of larger-scale eruptions that occurs at the neutral line from which the large-scale filament erupts. Large-scale eruptions are relatively uncommon (~1/day) and occur with relatively large-scale erupting filaments (~10^5 km long). Coronal jets are more common (>~100s/day), but occur from erupting minifilaments of smaller size (~10^4 km long). It is known that solar spicules are much more frequent (many millions/day) than coronal jets. Just as coronal jets are small-scale versions of large-scale eruptions, here we suggest that solar spicules might in turn be small-scale versions of coronal jets; we postulate that the spicules are produced by eruptions of ``microfilaments'' of length comparable to the width of observed spicules (~300 km). A plot of the estimated number of the three respective phenomena (flares/CMEs, coronal jets, and spicules) occurring on the Sun at a given time, against the average sizes of erupting filaments, minifilaments, and the putative microfilaments, results in a size distribution that can be fit with a power-law within the estimated uncertainties. The counterparts of the flares of large-scale eruptions and the JBPs of jets might be weak, pervasive, transient brightenings observed in Hinode/CaII images, and the production of spicules by microfilament eruptions might explain why spicules spin, as do coronal jets. The expected small-scale neutral lines from which the microfilaments would be expected to erupt would be difficult to detect reliably with current instrumentation, but might be apparent with instrumentation of the near future. A full report on this work appears in Sterling and Moore 2016, ApJL, 829, L9.

Overview

At least many coronal jets appear to be miniature versions of large-scale eruptions. Specifically, both result from eruption of filament-like features: normal filaments in the case of large-scale eruptions, and smaller-scale ``minifilaments'' in the case of coronal jets. Also, both phenomena have brightenings at their bases: solar flares in the filament eruptions, and JBPs at the base of the coronal jets. This suggests that the two phenomena, filament eruptions and flares on the one hand, and coronal jets and JBPs on the other, are the same phenomenon but on different size scales.

Besides size scale, another difference between these two features is their occurrence rate: the number of coronal jets is much larger than the number of large-scale eruptions. Spicules are also transient, jet-like phenomena, and are far more common than either large-scale eruptions or coronal jets. And, recent intriguing recent ideas for their formation not withstanding (e.g. DePontieu et al. 2004, Martinez-Sykora et al. 2017; see, e.g., Beckers 1998 and Sterling 2000 for older ideas), a full explanation for their cause is still outstanding.

A natural question to ask is whether the relationship between size-scale and occurrence rate of the relatively-small number of large-scale eruptions and the larger number of smaller-scale coronal jets, extends to the much-more-frequent and smaller-size-scale spicules. We explore this idea by plotting the size scales (or expected size scales) of the filament-like features the erupt to form CMEs, jets, and spicules, against the measured occurrence rate of CMEs, jets, and spicules. We then see whether this relationship between these quantities can be fit with a power law.

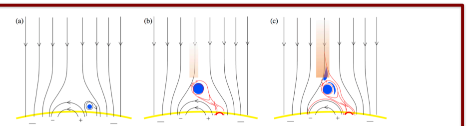

Figure 1. Schematic of minifilament eruption leading to a coronal jet (modified version of Sterling et al. 2015; Figure 2). Black lines show magnetic fields, with arrows indicating polarities. Red lines indicate fields that have undergone magnetic reconnection, with red crosses showing reconnection locations. (a) Initially, a minifilament (blue) sits in a compact sheared bipole adjacent to a larger less-sheared bipole, all inside surrounding open field. (b) An unspecified agent triggers the minifilament field to erupt like a larger-scale filament eruption. Reconnection at the left-side red X between the envelope of the erupting-minifilament field and the open coronal field results in a hot jet (shaded-orange strip), visible as a hotter-EUV (e.g., 211 Å) or X-ray jet. Reconnection interior to the exploding minifilament field at the right-side red X results in the JBP (bold red semicircle), analogous to a solar flare in large-scale filament eruptions. (c) If the minifilament erupts far enough into the opposite-polarity open-field region, then the left-side reconnection "eats away" enough of the enveloping outer field surrounding the minifilament in the core for minifilament material to be expelled along the vertical field, resulting in a cool (e.g., EUV 304 Å) jet component. See Sterling et al. (2015, 2016) for details.

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Large-Scale Eruptions ("filament eruptions")

By "large-scale eruptions," we mean the typical magnetic eruptions that make often result in coronal mass ejections (CMEs) and solar flares. Typically these begin with eruption of a filament, which range in size 3 x 10^4 - 1.1 x 10^5 km (Bernasconi et al. 2005), from a magnetic neutral line. A flare then grows along the neutral line from which the filament erupted. We can make a rough estimate for the number of large-scale eruptions on the Sun at any given time in this way: there are 0.5—6 CMEs/day (Yashiro et al. 2004; Chen 2011), and the duration of a strong-flare's duration is ~20 min (Verong et al. 2002); from this, we deduce that there are ~0.03 CME-producing typical filament eruptions occurring on the Sun at any given time. (That is, looking at the Sun randomly 1/0.03 ~ 33 independent times about a day's time scale should show on average one large-scale filament eruption occurring.)

Coronal jets ("minifilament eruptions")

Coronal jets are are seen in X-ray and EUV coronal images. They have a geyser-like appearance and can reach >50,000 km with widths of ~8000 km, with lifetimes of ~10 min (Savcheva et al. 2007); these numbers are for polar coronal-hole jets, but they are seen all over the Sun (e.g., Shimojo et al. 1996). Recent investigations indicate that many, if not all, coronal jets result from eruptions of small-scale filaments ("minifilaments") of size ~8000 km (Sterling et al. 2015). (Figure 1.) These jets have a brightening at their base (jet-base bright point, JBP), analogous to flares, and the jets/minifilament eruptions occur on magnetic neutral lines (e.g. Huang et al. 2012, Panesar et al. 2016), analogous to large-scale filament eruptions. Jet-producing erupting miifilaments have sizes ~8000 km; and based on observed rates and lifetimes in polar coronal holes (Savcheva et al. 2007), we estimate that there are ~5 jets occurring on the Sun on average at any given random time.

Results and Discussion

Figure 2 shows the number of eruption of filament-like features on the Sun at any given time, plotted against the size of the filament-like features, where the numbers are as described/estimated in the previous panels. We find that, within the uncertainty ranges (Sterling & Moore 2016), the values all fall on the same power law line. This supports that the filament-like-eruption mechanism that drives large-scale eruptions and coronal jets, could drive ~10% — 100% of spicules, and still be consistent with fitting the power-law distribution. A counterpart of the putative spicule-producing microfilament eruptions to the flares and the JBPs of, respectively, filament and minifilament eruptions, might be brightenings sometimes seen in near-limb Ca II images (Figure 3).

So far however, the existence of spicule-producing microfilaments is totally speculative, and the nature of the Ca II brightenings is uncertain. DKIST and future Sun-observing space missions should improve our knowledge of the nature of solar phenomena such as large-scale eruptions, coronal jets, and spicules.

Acknowledgements

This investigation was supported by NASA's HGI program, and the Hinode project. We thank T. Tarbell for assistance with the SOT images.

Spicules ("microfilament eruptions"??)

Spicules are extremely common chromospheric jet-like features reaching heights ~5000 km. We speculate that, if they results from even-smaller-scale eruptions of filament-like features ("microfilaments"), the erupting-microfilaments would have widths similar to spicule widths, or ~300 km (Pereira et al. 2012). Historical measurements place the number of spicules on the Sun at any given time as ~(9.3—50.0) x 10^4 (Athay 1959, Lynch et al. 1973).

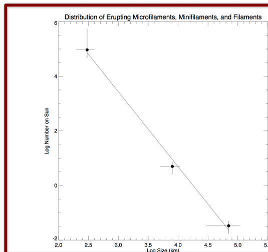

Figure 2. Distribution of estimated number of erupting-filament-like features on the Sun at any given time, as a function of the size of those erupting features. Right, middle, and left points are for filament eruptions driving CMEs and typical solar flares, minifilament eruptions driving coronal jets and JBPs, and postulated microfilament eruptions that would drive spicules. "Error" bars show measured or estimated ranges of the plotted values. We used ±50% of the plotted values as guesses for the uncertainties in the number-on-Sun values, except the upper number for the erupting microfilaments is from Lynch et al. (1973). See the text for uncertainties in sizes. The line (slope = −2.7) is the least-squares best fit to the three points without consideration of uncertainty weights.

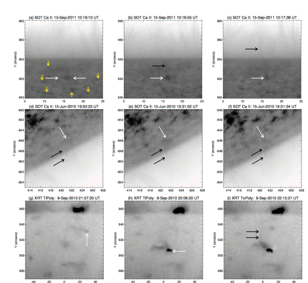

Figure 3. (a)–(c) Hinode SOT Ca II color-reversed images (~0 1 pixel−1 resolution) of a polar coronal hole near the limb, showing on-disk "Ca II brightenings" and spicules (white/black arrows show brightenings/spicules). Yellow arrows show examples of additional brightenings that might also be at roots of spicules. Brightenings between white arrows in (a) evolve to a more-concentrated brightening indicated by arrow in (b), which fades significantly by (c). Black arrows in (b) and (c) show a strand of a Type II spicule emanating from the Ca II brightening. (d)–(f) Same as (a)–(c), but for a quiet-Sun region near the south pole limb. Arrows in accompanying animations show additional base brightening/spicule examples. (g)–(i) Images from Hinode/XRT, showing X-ray jet #12 in Sterling et al. (2015, Extended Data Figure 2 of that paper); here, we show the same animation as in that paper, but with colors reversed to emphasize morphological similarities with the SOT features in (a)–(f); white/black arrows show JBP examples and a jet spire, respectively, where the JBP in (g) is of a weaker jet in the background. North is upward and west is right. Intensity scaled to highlight faint features, resulting in saturation of some features. (Animations available in Sterling & Moore 2016.)